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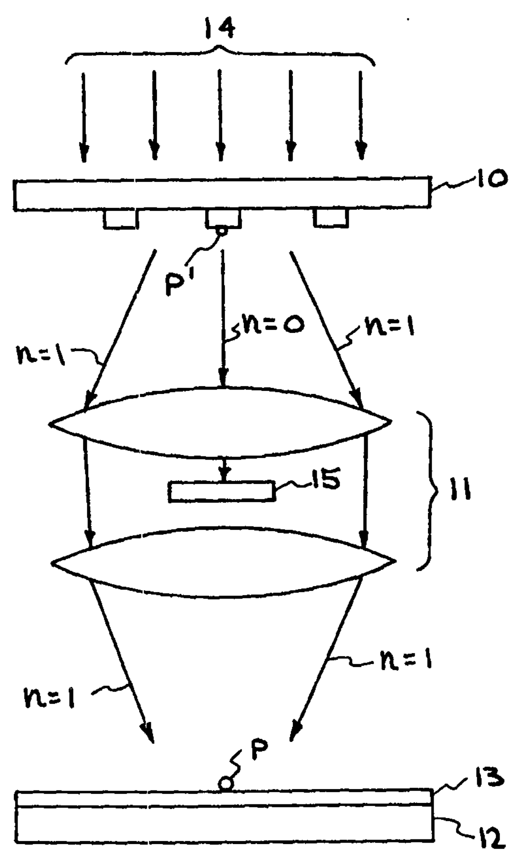
(54) Title: SUB–MICRON PATTERNING USING OPTICAL LITHOGRAPHY

(57) Abstract

Traditional optical lithography is used to generate a high resolution pattern in a resist (13) on a substrate (12). The process recognizes that the fabrication of periodic and quasi–periodic patterns requires specific Fourier components and the absence of undesired Fourier components in some cases. The process involves determining which Fourier components are desired and analyzing the Fourier transform of the pattern by comparing the desired electric field pattern to the electric field pattern at the mask. Various techniques can be used to generate the desired Fourier components including the use of a mask (10) or filters (15) or a combination of the two.



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SUB-MICRON PATTERNING USING OPTICAL LITHOGRAPHY

The United States Government has rights in this invention pursuant to Contract No. W-7405-ENG-48 between the United States Department of Energy and the University of California for the operation of Lawrence Livermore National Laboratory.

BACKGROUND OF THE INVENTION

The present invention relates to optical lithography, particularly to patterning using optical lithography, and more particularly to sub-micron patterning using optical lithography for uses in applications such as giant magnetoresistive devices and devices using field emission tips, such as flat panel displays.

In traditional optical lithography, a mask pattern, sometimes called a reticle, is imaged onto a substrate, such as silicon or glass, using imaging optics, as shown in Figure 1. Generally, the imaging process demagnifies the mask pattern onto the substrate, at anywhere from 1 to 10X demagnification, and the substrate is coated with a material sensitive to the imaging radiation, as shown in Figure 1. This material is often called photosensitive resist, or simply, resist. Under ideal conditions and on imaging systems with infinite resolution, the image that is projected onto the substrate is an identical copy of the pattern on the reticle, as illustrated in Figures 2A and 2B, wherein the minimum feature sizes (mfs) are the same. For purposes of illustration, the imaging system is assumed to have unity demagnification. However, under practical conditions, the imaging system does not have infinite resolution and this degrades the image pattern at the substrate. This degradation is illustrated in Figure 3 which illustrates an electric field pattern at the substrate for an imaging system with finite resolution. The practical resolution of the imaging system is determined by the imaging wavelength, λ, and the numerical aperture of the system. Under aberration-free conditions, the practical resolution of the imaging system (i.e., the minimum feature size that can be recorded at

the substrate) is approximately mfs = $0.7\lambda/(na)$, where (na) is the numerical aperture of the imaging system. A present-day state-of-the-art optical imaging system for lithography has a numerical aperture (na) of approximately 0.5 and utilizes a wavelength (λ) of approximately 250nm. This results in a practical resolution limit of 350nm which is too large for certain devices, such as giant magnetoresistive (GMR) sensors for ultra-high density magnetic storage or field emission tips for flat panel displays, high speed electronics or microwave devices.

Recently, significant effort has been directed towards increasing the practical resolution of optical imaging systems for the manufacture of integrated circuits. These technologies include the use of phase shifting masks and/or modifications to the mask illumination by apodizing the condenser optics (i.e., so called "off-axis illumination"). These techniques can improve the practical resolution by nearly a factor of approximately 1.5 for specific conditions. However, the complexity of modern integrated circuits dictates that these techniques be applicable to a wide variety of pattern shapes and densities. This places severe restrictions on the fabrication techniques. In addition, modern demagnifying optical lithographic tools and phase shifting masks often require monochromatic sources which are generally less intense than broadband sources. As a result, the actual improvement in resolution for the manufacture of complex integrated circuits is limited and the device throughput is reduced. For these reasons, these techniques have not been readily accepted by the manufacturing community.

Giant magnetoresistive (GMR) sensors for ultra-high density magnetic storage are very promising and offer advantages over traditional display and information storage technology. Also, various devices using field emission, such as flat panel displays and random access memory (RAM) devices, such as a dynamic random access memory (DRAM), a static random access memory (SRAM), and a magnetic random access memory (MRAM) are being actively developed. However, these device concepts may require the ability to fabricate periodic or quasi-periodic structures with sub-quarter micron features. While it is possible to fabricate these devices in a research environment to test these devices, traditional high resolution fabrication technologies, such as proximity print x-ray, EUV lithography, or electron and ion beam

lithographies are immature technologies, are very slow or are too expensive for large scale, commercial manufacturing.

New advanced devices, such as GMR devices and field emission devices will require the fabrication of sub-micron structures. Fortunately, the device geometries are very specific and fabrication processes can be tailored to meet their needs. For GMR devices, an array of rectangular (or near rectangular) patterns, approximately 20-500nm in width and 100-5000nm in length are required, see Figure 4. For field emission devices, an array of sub-500nm (10-500nm) dots spaced every 200-2000nm is required, see Figure 5. These dimensions would normally be beyond the resolution of traditional optical imaging systems. The production of a periodic array of lines or dots (such as those patterns that may be employed to fabricate sub-quarter micron structures for GMR and field emission devices) has been accomplished by interfering two laser beams, as illustrated in Figure 6A. This technique, called laser interference lithography, has been employed to fabricate field emission devices for flat panel displays. The minimum feature size (mfs) that is produced with this process is mfs = $\lambda / 2 \sin(\theta)$, θ being the angle illustrated in Figure 6A. This is a substantial improvement over the Figure 3 mfs = $0.7\lambda/(na)$. Laser interference lithography employs a laser beam and relies on the coherent properties of the laser to produce a sinusoidal pattern at the substrate. The throughput of the laser interference lithography process is generally limited by the practical power limitations in the laser beam. As another practical matter, the electric field pattern produced at the substrate is a sinusoidal pattern on a constant ("DC") background when the power in the two laser beam arms is not identically balanced. This is illustrated in the electric field pattern of Figure 6B. This background exposure limits the latitude of this process. Finally, the structure produced by laser interference lithography is periodic everywhere and it is difficult to produce an arbitrary pattern.

In an optical imaging system, the light (or radiation) diffracted by the reticle (mask) is captured by the imaging optics and projected onto the substrate, previously shown in Figure 1. The light diffracted by the reticle can be identified by its Fourier expansion:

$$E_r(x) = \sum_n B_n \exp(ik_n x)$$

where $E_r(x)$ is the electric field of the diffracted light from the reticle as a function of position, x, B_n is the electric field amplitude of the n^{th} diffracted order, and k_n is the reciprocal wave vector, equal in magnitude to $2\pi n / p_r$, where p_r is the period of the pattern on the reticle. The "DC" or n = 0 diffracted order component is the light that travels straight through the reticle and onto the imaging optics, whereas the higher order Fourier components (i.e., the $n \neq 0$ terms in the Fourier expansion) are "bent" or "diffracted" by the pattern on the reticle. Many of these diffracted orders are also incident upon the imaging optics, but some higher order terms are lost because they are diffracted to larger angles than the optics can collect, as shown by n = 2 in Figure 1. The pattern that is recorded on the substrate is the linear combination of the Fourier components that are captured by the imaging optics and projected onto the substrate. To accurately copy the pattern of the mask onto the substrate, it is necessary to capture all of the Fourier components. However, by this invention, it is possible to fabricate a different pattern on the substrate by modifying or filtering the Fourier components and this process does not require a coherent laser source. For example, it has been found that it is possible to fabricate a grating on the substrate with half the period of the original grating on the mask by suitably tailoring the power in the diffracted orders. This invention sets forth and identifies the techniques for the fabrication of sub-quarter micron structures for GMR structures, flat panel displays, and RAMs using optical imaging of larger structures and modifying their Fourier transform. Thus, the present invention involves a process whereby traditional optical lithography generates the desired high resolution pattern required for GMR or field emission devices. The advantages of this approach are that 1) it can be a high throughput process suitable for large scale manufacturing, and 2) it relies on technologies that have already been developed for the mature semi-conductor manufacturing industry.

SUMMARY OF THE INVENTION

The present invention is directed to a process involving sub-micron patterning using optical lithography.

A further object of the invention is to provide a process for sub-micron patterning for giant magnetoresistive or field emission devices using optical lithography.

Another object of the invention is to provide a process which enables the fabrication of periodic and quasi-periodic patterns, such as for GMR and field emission devices, by utilizing specific Fourier components and, in some cases, eliminating other Fourier components.

Another object of the invention is to provide a process whereby very high resolution, periodic patterns can be fabricated using optical lithography by creating an electric pattern with the required Fourier components.

Another object of the invention is to provide a process which involves maximizing the energy in desired Fourier components while minimizing the amount of energy in undesired Fourier components.

Another object of the invention is to enable the creation of an electric field pattern by maximizing the energy in desired Fourier components while minimizing the energy in undesired components using optical lithography without the use of a laser.

Other objects and advantages of the present invention will become apparent from the following description and accompanying drawings. The present invention is based on the recognition that the fabrication of periodic and quasi-periodic electric field patterns, such as for GMR and field emission devices, requires the existence of desired Fourier components in the electric field, and in some cases, the absence of undesired Fourier components. This invention recognizes that very high resolution, periodic and quasi-periodic patterns can be fabricated using optical lithography by creating an electric field pattern with the required Fourier components. The invention involves techniques that may be employed to maximize the energy in these desired Fourier components while minimizing the amount of energy in the undesired components. Also, the invention utilizes optical imaging for the fabrication of sub-micron structures for GMR and field emission devices, for example, and does not require a laser with monochromatic illumination and/or spatial coherence. Advantages provided by the present invention include a high throughput process suitable for large scale manufacturing, and reliance on technologies that have already been developed for the mature semiconductor manufacturing industry. The invention can be carried out using different techniques for generating the required Fourier components. A first technique uses a

reticle (mask) that is specifically fabricated to generate the desired Fourier components. A second technique utilizes filters (apodizers) in the imaging system to adjust the amplitudes of the diffracted Fourier components so that when they recombine at the substrate they will produce the desired pattern. A third technique involves producing the desired electronic field pattern at the substrate by combining the first and second above-described techniques, which may include using partially transparent filters or wave plates. Thus, it is understood that the present invention involves a process: using optical lithography for the fabrication of sub-quarter micron structures for field emission devices by: 1) using a specially fabricated reticle (with the appropriate phase shift and line to space ratio) to generate the necessary Fourier coefficients so as to generate a pattern at the substrate with a smaller spatial period; or 2) modifying the diffracted light from a reticle (through either modifications to the condenser illumination or by attenuating or shifting the relative phase of the Fourier components) to generate a pattern at the substrate with a smaller spatial period; or a combination of 1) and 2) above.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the disclosure, illustrate apparatus for carrying out the process of the invention and, together with the description, serve to explain the principles of the invention.

Figure 1 schematically illustrates a prior art optical lithography system generally used in semiconductor manufacturing.

Figures 2A and 2B illustrate an electron field pattern of mask and substrate under ideal (infinite resolution) imaging conditions.

Figure 3 illustrates a practical electron field pattern from a real (finite resolution) imaging system.

Figure 4 illustrates an embodiment of a GMR structure which can be produced using the process of the present invention.

Figure 5 illustrates an embodiment of a field emission device which can be produced using the process of this invention.

Figures 6A and 6B illustrate a laser interference lithography system and the electric field pattern of the system at the substrate.

Figure 7 schematically illustrates an optical lithography system similar to Figure 1, but modified in accordance with the present

invention, which carries out imaging with the energy in the $n = 0$ component blocked.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed to sub-micron patterning using optical lithography and particularly to a process for sub-micron patterning for giant magnetoresistive (GMR) devices, such as sensors for ultra-high density magnetic storage, or for field emission tips for flat panel displays, DRAMs, SRAMs, and MRAMs. The advantages of this process are: 1) it can be a high throughput process suitable for large scale manufacturing, and 2) it relies on technologies that have already been developed for the optical lithography industry.

In an optical imaging system, the pattern that is recorded on the substrate is the linear combination of the Fourier components that are captured by the imaging optics projected onto the substrate. To accurately copy the pattern of the mask or reticle onto the substrate, it is necessary to capture all of the Fourier components. However, it has been discovered that it is possible to fabricate a different pattern on the substrate by modifying or filtering the Fourier components and this process does not require a coherent laser source. For example, it has been found that it is possible to fabricate a grating on the substrate with a quarter, third, or half the period of the original grating on the mask by suitably tailoring the power in the diffracted orders. This invention sets forth and identifies the techniques for the fabrication of sub-quarter micron structures for GMR and field emission devices, for example, using optical imaging of larger structures and modifying the energy in the components of the Fourier expansion of the diffracted light.

The basis of the present invention is the recognition that the fabrication of periodic and quasi-periodic patterns (such as for GMR or field emission devices), requires the existence of specific (desired) Fourier components and, in some cases, the absence of other (undesired) Fourier components. The present invention, as described in detail hereinafter, involves:

1) the recognition that very high resolution, periodic patterns can be fabricated using optical lithography by creating an electric field pattern with the required Fourier components;

2) techniques that may be employed to maximize the energy in the desired Fourier components while minimizing the amount of energy in the other (undesired) components; and

3) a process which does not require a laser with monochromatic illumination and/or spatial coherence, as in the laser interference lithography technique.

Figure 1 illustrates a conventional (prior art) optical lithography system basically composed of a mask or reticle 10, imaging optics 11, a substrate 12 having a resist 13 thereon which is sensitive to the imaging radiation. Incident radiation indicated at 14 passing through mask 10 is diffracted and the Fourier components indicated by arrows n = 1 and -1 and n = 2 and -2, with non-diffracted Fourier component being indicated by arrow n = 0 which passes directly through the imaging optics 11 onto the substrate 12. The diffracted radiation (Fourier components) of arrows n = 1 and n = -1 passes through optics 11 and is produced as a reformed image on substrate 12, as indicated by the arrows. Diffracted radiation (Fourier components) from mask 10 as indicated by arrows n = 2 and n = -2 is outside the numerical aperture of the imaging optics 11 and thus is not reformed onto substrate 10.

In an imaging system, as shown in Figure 1, there exists a one-to-one spatial correspondence between every point p on the substrate 12 and its counterpart, point p', on the mask or reticle 10. Under normal imaging conditions, the electric field at point p is uniquely determined by the electric field at point p'. The electric field pattern at point p is simply the combination of all the Fourier components that are generated by point p' and which are transported through the imaging optics 11 of the optical imaging system. All the Fourier components for each wavelength from point p' are added to generate the pattern at p. In a conventional optical imagine system with a conventional mask pattern as illustrated in Figure 2A, the incident radiation 14 and mask 10 produce the Fourier components that generate the pattern recorded in either Figure 2B or Figure 3 (depending upon the numerical aperture of the imaging optics 11 of the system. However, by modifying the amplitudes in the individual Fourier components, a different pattern will be produced at the substrate 12.

The first step in the process of this invention is to determine which Fourier components are desired at the substrate. This

is determined by analyzing the Fourier transform of the desired pattern at the substrate. Assuming that the desired pattern is periodic with a period, p_d, then the Fourier expansion of the desired pattern is:

$$E_d(x) = \sum_n A_n \exp(ik_n x)$$

where $E_d(x)$ is the electric field of the desired pattern as a function of position, x, A_n is the electric field amplitude of the nth diffracted order, and k_n is the reciprocal wave vector, equal in magnitude to $2\pi n / p_d$. Comparing this electric field pattern to the electric field pattern from the reticle:

$$E_r(x) = \sum_n B_n \exp(ik_n x)$$

it is possible to fabricate the desired electric field pattern from the electric field pattern at the reticle provided the period at the reticle, p_r, is an integer multiple of the desire pattern, p_d, and the Fourier coefficients from the reticle, B_n, are made to match their corresponding Fourier coefficients for the desired pattern, A_n. Matching the Fourier coefficients can be accomplished by 1) modifying the phase and amplitude of the diffracted electric field pattern from the mask through modifications to the line-to-space ratio on the mask and the phase shift through the lines (relative to the spaces), and 2) by filtering (or attenuating) the diffracted electric field pattern in the imaging system through apodizers.

The attenuation (filtering) approach is illustrated with reference to Figure 7 which shows an imaging system similar to that of Figure 1 and thus corresponding components have been given similar reference numerals. The difference in the two imaging systems is that Figure 7 illustrates the n = 0 Fourier component blocked, such as by an attenuating apodizer 15 placed in the imaging optics 11. The following example will illustrate this approach, and for simplicity, first consider the optical system as being illuminated with a monochromatic source to produce the incident radiation 14, and with the n = 0 Fourier component blocked as indicated at apodizer 15. Under this condition, the electric field produced at point p is now a combination of the new set of Fourier components. This new set of Fourier components is the original set of components generated at point p', but with the n = 0 component removed. By removing this one Fourier component, it is

possible to alter the electric field pattern at point p and therefore, alter the pattern recorded at the substrate. In the example shown in Figure 7, the electric field at point p is a combination of the $n = 1$ and $n = -1$ Fourier components. The resulting electric field pattern at the substrate in Figure 7 is a period pattern with a period smaller than the original (mask) pattern. By blocking the $n = 0$ component and combining the $n = \pm 1$ Fourier components, an electric field pattern with half the period of the original pattern is generated; i.e., a new pattern with half the minimum feature size of the original pattern is generated at the substrate. By combining the appropriate Fourier components, it is possible to generate electric field patterns which are smaller than the original pattern by an integral divisor (i.e., 2 times smaller, 3 times smaller, and 4 times smaller, etc.).

Two general techniques are used to generate the required Fourier components. The first technique uses a reticle (mask) that is specifically fabricated so as to generate the desired Fourier components. For example, it is possible to eliminate the energy in the $n = 0$ component by producing a reticle with a 1:1 line-to-space ratio and a π phase shift. Such a reticle maximizes the energy in the odd Fourier components (i.e., n = odd) and will produce a pattern at the substrate with half the spatial period of the original reticle. It is also possible to fabricate patterns on the substrate with a spatial period equal to one third, one forth, etc., of the original reticle, by using a generalized version of this technique (i.e., modify the energy distribution in the Fourier components by fabricating a grating with the appropriate phase shift and line-to-space ratio). To make this technique applicable for a broadband source, it may be necessary to add an apodizer to the imaging system (discussed below). This is because the reticle's π phase shift will be satisfied at only one wavelength and other wavelengths will have some non-zero energy in the $n = 0$ diffracted order. These non-zero terms will degrade the process and reduce process latitude.

The second technique to fabricate these structures is to use filters (apodizers) in the imaging system. The purpose of these filters is to adjust the amplitudes of the diffracted Fourier components so that, when they combine at the substrate, they will produce the desired pattern. Figure 7 illustrates a simple example of this technique. In Figure 7, a physical structure actually blocks the $n = 0$ diffracted order and

only the n = ± 1 terms are transmitted. In general, more diffracted orders than simply the n = 0, ± 1 terms exist in the imaging system. It is also possible to modify the ratio of the amplitudes between these terms by placing partially transparent filters in the beam paths. For example, the n = ± 3 terms can be enhanced (relative to the n = ± 1 terms) by attenuating the n = ± 1 terms with a partially transparent filter in the beam paths for the n = ± 1 terms. This will have the effect of enhancing the contributions from the n = ± 3 terms relative to the n = ± 1 terms.

It is possible to produce the desired electric field pattern at the substrate by combining the two techniques described above. In some situations, this may be desired to enhance the latitude and the throughput of the process. An additional method is to shift the relative phase of the diffracted orders. This can be easily done by introducing a quarter or half wave plate in place of the attenuating apodizer (beam block) illustrated in Figure 7, or by combining these effects by using a partially transmitting apodizer with a quarter or half wave plate.

The system illustrated in Figure 7 can be utilized to carry out the process of this invention to produce devices such as illustrated in Figures 4 and 5. Figure 4 illustrates a GMR structure wherein an array of rectangular members 20 are formed on a substrate 21. The sub-micron array of members 20 are constructed of magnetic materials, or as illustrated, alternating layers 22 of magnetic materials and layers 23 of non-magnetic materials. The array of members 20 may be constructed so that each pattern has, for example, a width, w, of 20-500nm and a length, l, of 200-5000nm. Figure 5 illustrates a flat panel display, for example, wherein an array of sub-micron field emission tips or pillars 30 are formed on a substrate 31. The tips or pillars 30 typically have a dimension, d, of 10-500nm and are spaced every 200-2000nm, as indicated at s.

It has thus been shown that the present invention provides for sub-micron patterning using optical lithography, and is particularly applicable for sub-micron patterning for GMR and field emission devices, such as flat panel displays and RAM devices. The process of this invention enables the use of traditional optical lithography to generate the desired high resolution pattern for GMR and field emission devices. This approach can be used in a high throughput process suitable for large scale manufacturing, and it relies on technologies that have already been

developed for the optical lithography industry. The process simply involves the generation of required Fourier components, and this is accomplished using two techniques. The first uses a mask that is specifically fabricated so as to generate the desired Fourier components, and the second uses filters (apodizers) in the imaging system to adjust the amplitudes of the diffracted Fourier components or physically blocks undesired Fourier components. Also, these two techniques can be combined to produce a desired electric field pattern at the substrate.

While specific examples have been set forth to illustrate and describe the principles of the invention, such are not intended to be limiting. Modifications and changes may become apparent, and it is intended that the invention be limited only by the scope of the appended claims.

CLAIMS

1. A process for sub-micron patterning using optical lithography, comprising:

directing a beam of radiation onto a patterned mask or reticle which passes and diffracts the beam to form a beam comprising a plurality of Fourier components;

imging the beam from the mask or reticle onto a substrate to produce a pattern on the substrate;

controlling the pattern produced on the substrate by maximizing the energy in desired Fourier components while minimizing energy in undesired Fourier components of the beam.

2. The process of Claim 1, wherein minimizing energy in undesired Fourier components is carried out by physically blocking the undesired Fourier components from reaching the substrate.

3. The process of Claim 1, wherein minimizing energy in undesired Fourier components is carried out by filtering certain of the Fourier components.

4. The process of Claim 1, wherein minimizing energy in undesired Fourier components is carried out by modifying the Fourier components reaching the substrate.

5. The process of Claim 1, wherein maximizing and minimizing energy in the Fourier components forms a grating on the substrate with a half, a third, a quarter, or other fraction of the period of the original grating on the mask by tailoring the power in the diffracted Fourier components.

6. The process of Claim 1, wherein maximizing and minimizing energy in the Fourier components is carried out by a combination of blocking or filtering certain Fourier and modifying the mask to generate the desired Fourier components.

7. The process of Claim 1, wherein maximizing and minimizing energy in the Fourier components is carried out by forming the mask so as to generate only the desired Fourier components.

8. The process of Claim 1, wherein maximizing and minimizing energy in Fourier components is carried out by modifying the ratio of the amplitudes between the Fourier components by placing a partially transparent filter in the beam paths.

9. The process of Claim 1, wherein maximizing and minimizing energy in Fourier components is carried out by shifting the relative phase of one or more of the diffracted Fourier components.

10. The process of Claim 9, wherein shifting the relative phase of the diffracted Fourier components is carried out by introducing a quarter, a third, or a half wave plate so as to be contacted by the undesired Fourier components.

11. The process of Claim 10, additionally including introducing a partially transmitting apodizer for use with the wave plate.

12. In an optical imaging system wherein a beam of radiation directed onto a patterned mask or reticle which passes and diffracts the beam to form a beam comprising a plurality of Fourier components, and the beam from the mask or reticle is imaged onto a substrate to produce a pattern on the substrate, the improvement comprising:

determining which Fourier components are desired at the substrate; and

forming a desired electric field pattern at the substrate.

13. The improvement of Claim 12, wherein forming a desired electric field pattern is carried out from a group of techniques consisting of fabricating the mask so as to generate desired Fourier components, blocking the passage of undesired Fourier components, filtering the Fourier components to adjust the amplitudes of the diffracted Fourier components, fabricating a grating on the substrate with half the period of the grating on the mask by tailoring the energy in the diffracted Fourier components, and a combination of two or more of the techniques.

14. The improvement of Claim 12, wherein the thus formed electric field pattern is utilized for producing high resolution, periodic patterns.

15. The improvement of Claim 12, wherein the thus formed electric field pattern is utilized in the fabrication of periodic and quasi-periodic patterns for giant magnetoresistive devices.

16. A process using optical lithography for sub-micron patterning of devices including giant magnetoresistive devices, flat panel displays and RAM devices using field emission tips, comprising:

determining the desired electric field pattern to be directed onto a substrate; and

controlling the Fourier components of a beam diffracted from a mask and imaged onto the substrate to produce the desired electric field pattern on the substrate.

17. The process of Claim 16, wherein controlling the Fourier components is carried out by physically blocking undesired Fourier components.

18. The process of Claim 16, wherein controlling the Fourier components is carried out by adjusting the amplitudes of the diffracted Fourier components by filtering the Fourier components.

19. The process of Claim 16, wherein controlling the Fourier components is carried out by fabricating the mask so as to generate the desired Fourier components.

20. The process of Claim 16, wherein controlling the Fourier components is carried out by selecting one or a combination of techniques from the group consisting of physically blocking the undesired Fourier components, filtering the Fourier components to adjust or modify the amplitude thereof, introducing a quarter or half wave plate in desired beam paths, fabricating the mask to generate the desired Fourier components, and shifting the relative phase of diffracted Fourier components by a combination of a partially transmitting apodizer with a quarter or half wave plate.

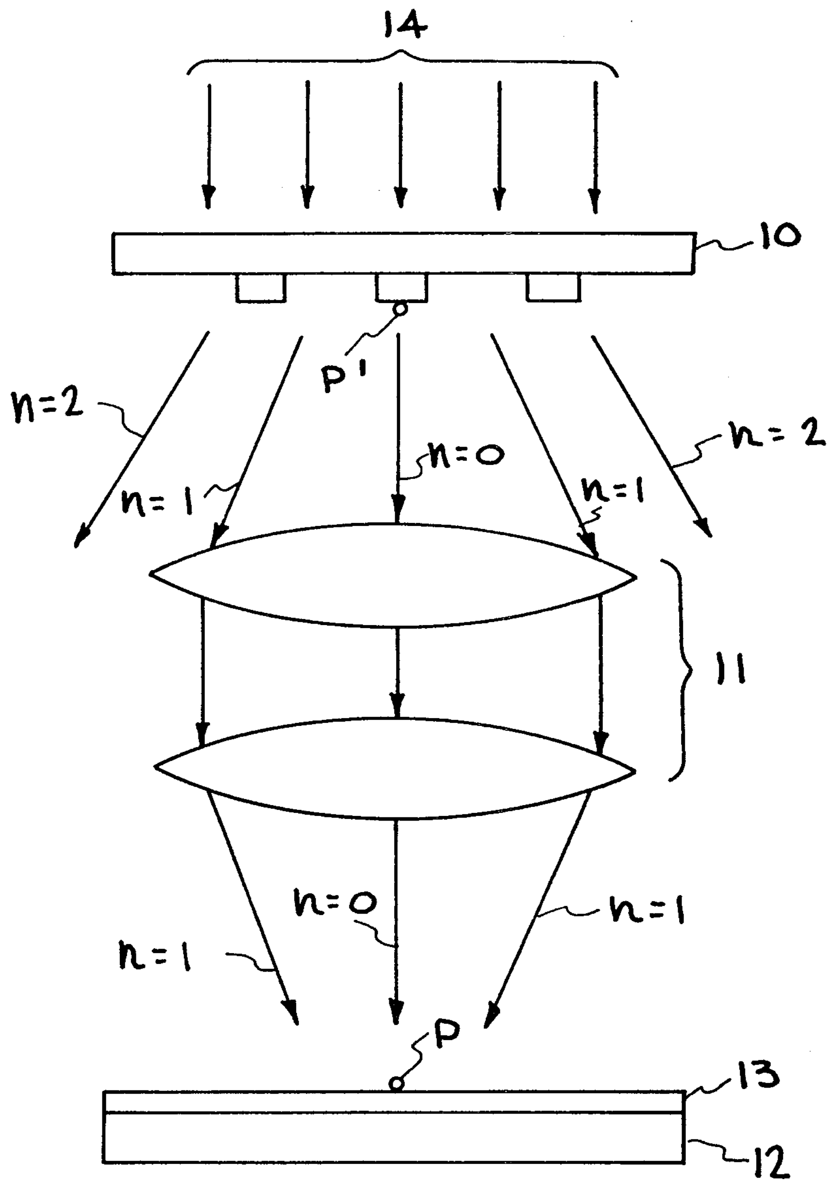

FIG. 1

(PRIOR ART)

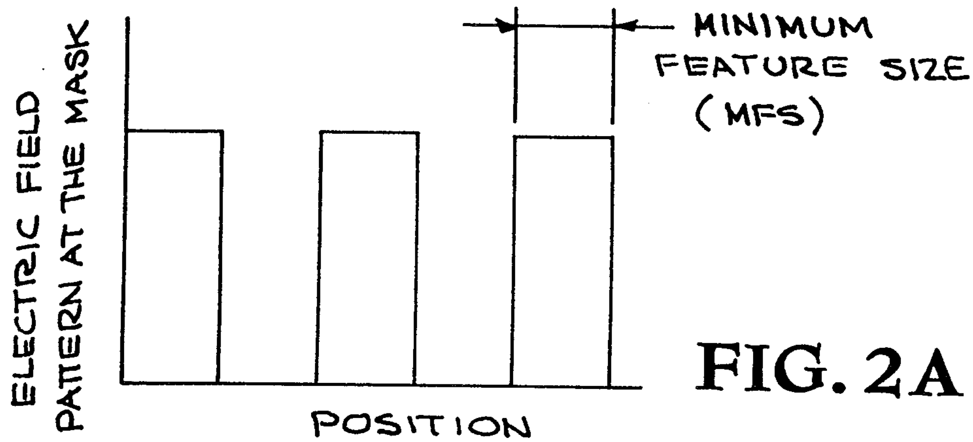

FIG. 2A

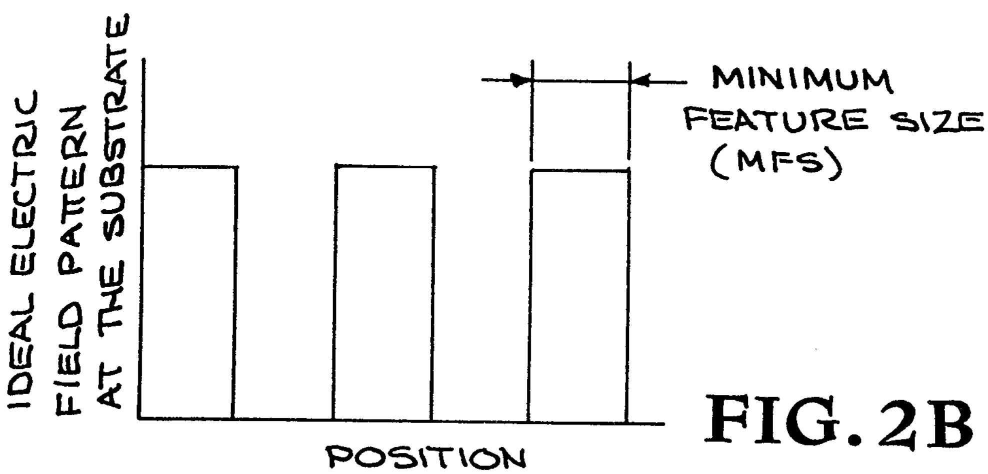

FIG. 2B

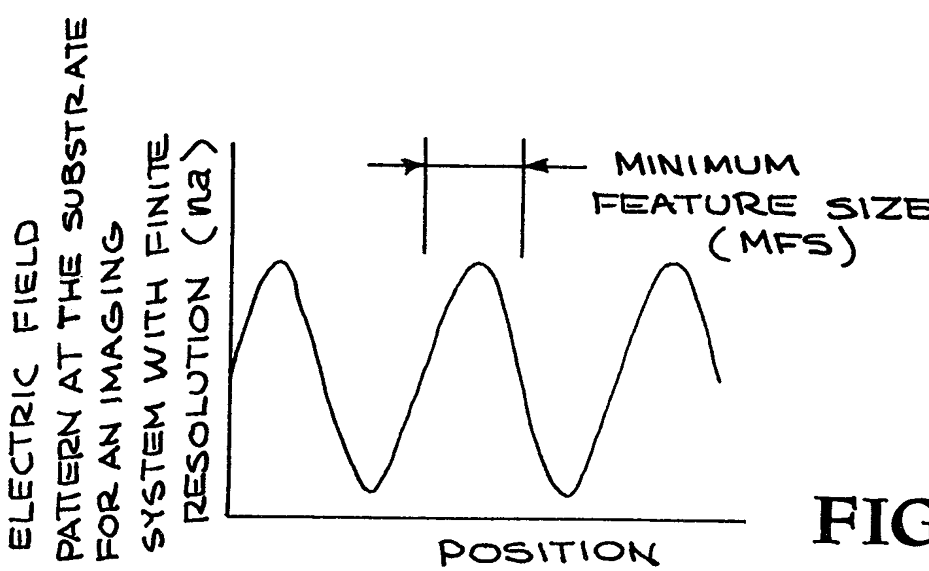

FIG. 3

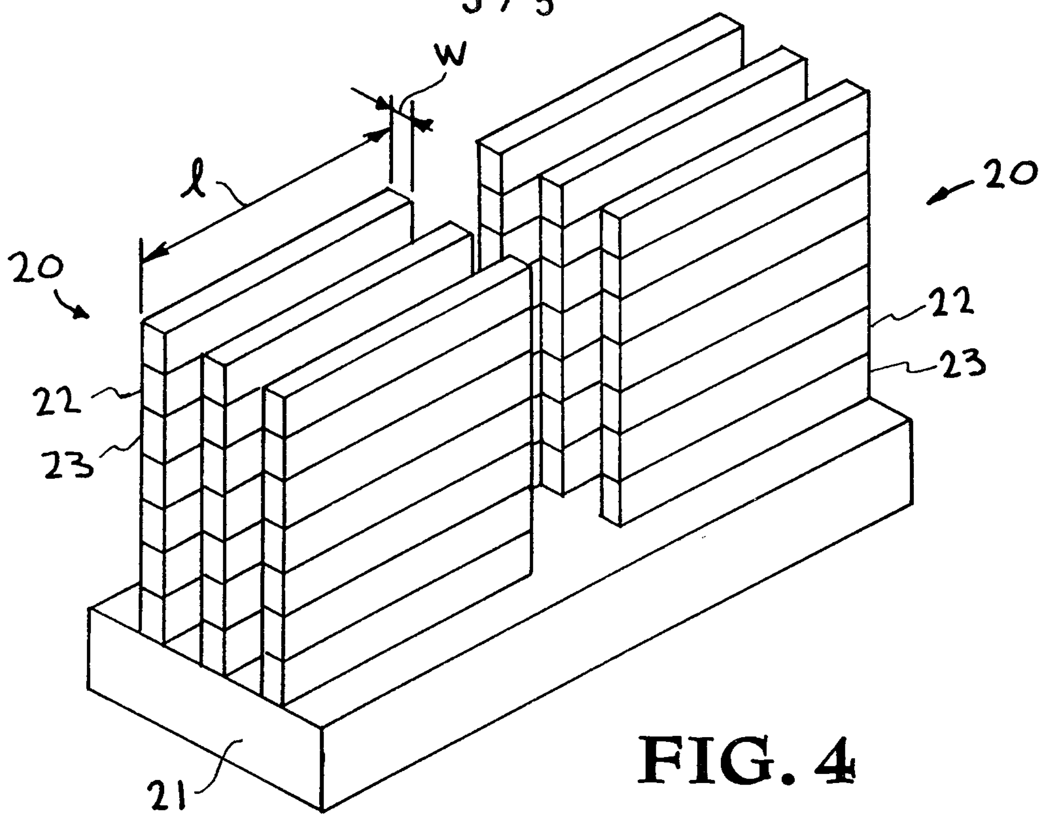

FIG. 4

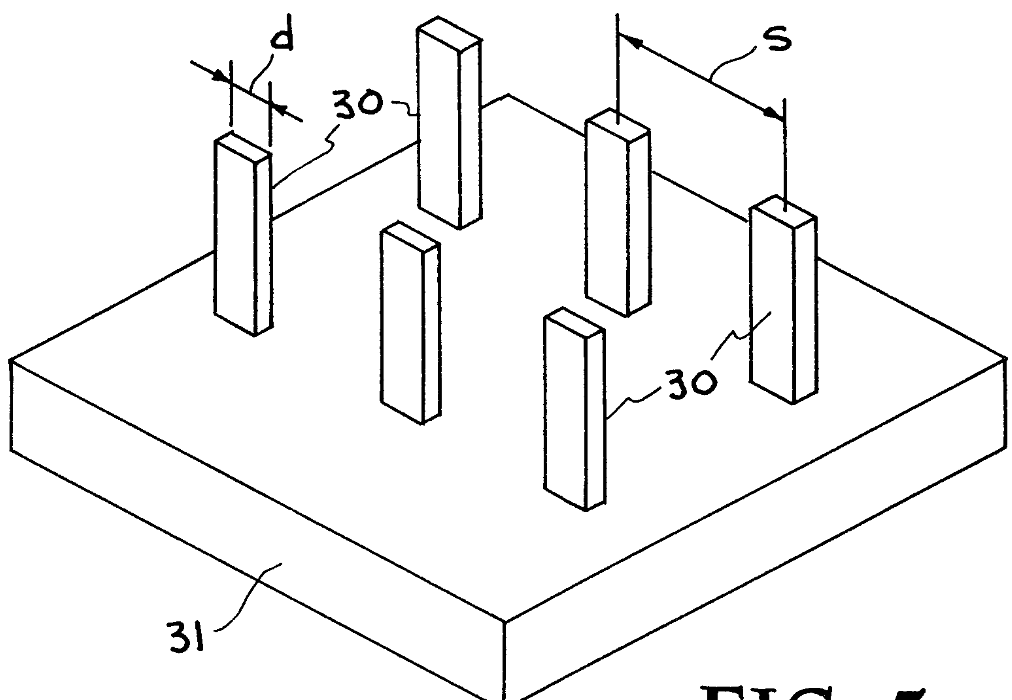

FIG. 5

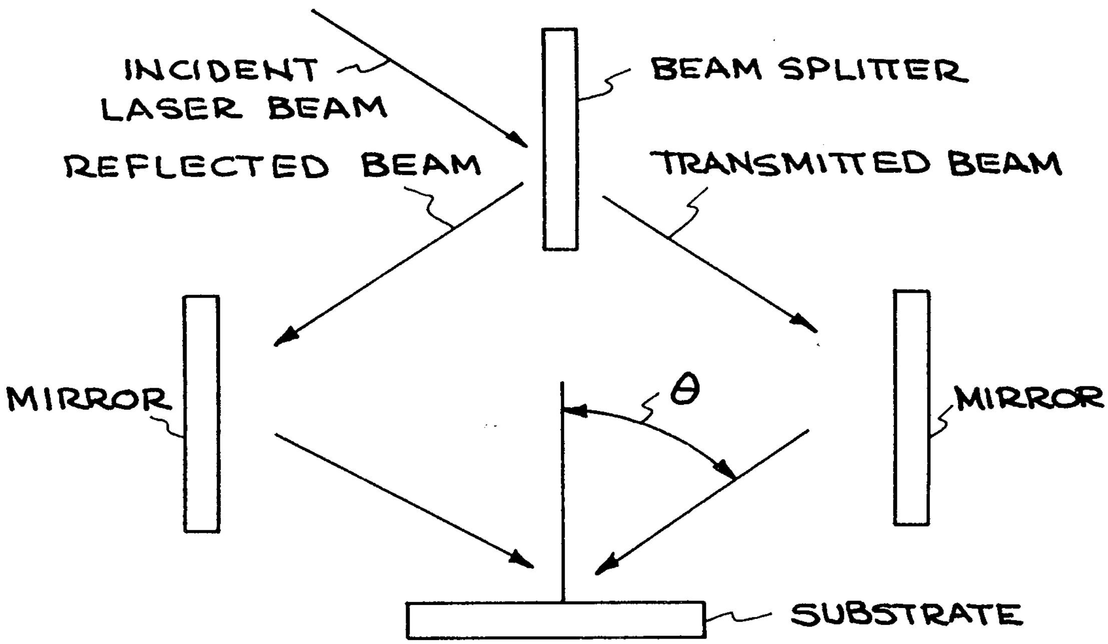
INCIDENT LASER BEAM
BEAM SPLITTER
REFLECTED BEAM
TRANSMITTED BEAM
MIRROR
θ
MIRROR
SUBSTRATE

FIG. 6A

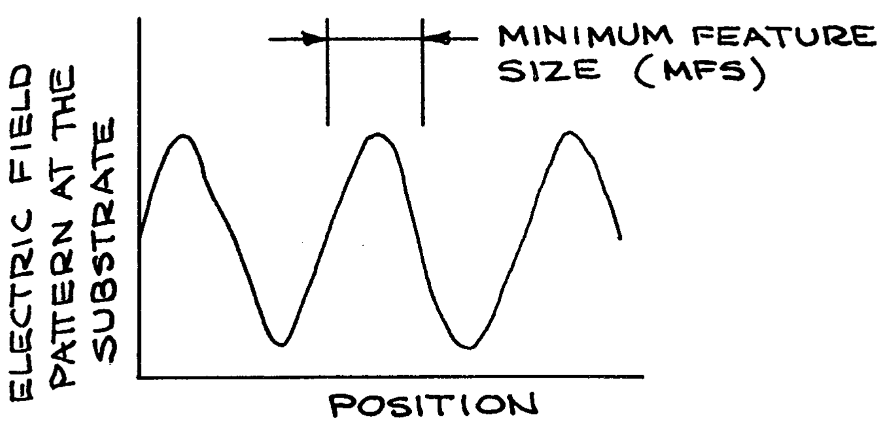
MINIMUM FEATURE SIZE (MFS)
ELECTRIC FIELD PATTERN AT THE SUBSTRATE
POSITION

FIG. 6B

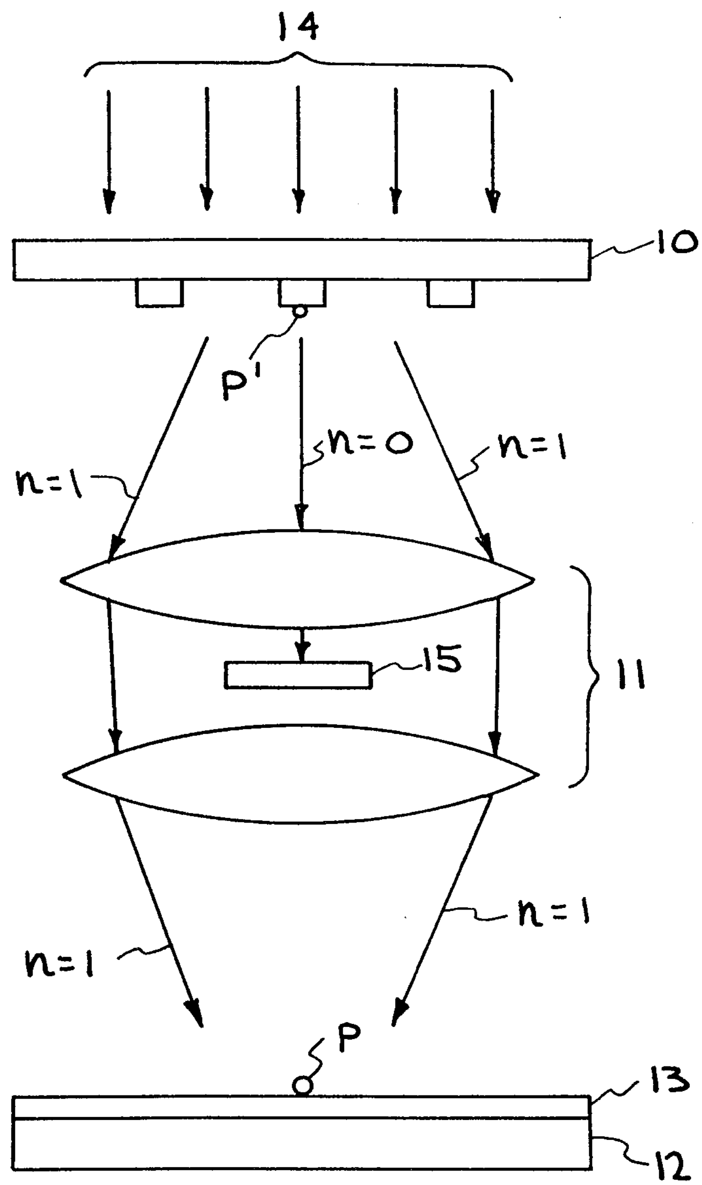

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/19157

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G03F 7/20
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 430/296, 327; 250/492.1, 492.2, 505.1; 359/559, 562, 564, 568, 590

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,947,413 A (JEWELL ET AL) 07 August 1990 (07-08-90), column 2, lines 40-52, column 4, lines 66-70, column 5, lines 44-65, column 6, lines 1-9 and column 9, lines 41-56.	1-5 -------------- 6-11, 13-15, 17-20
X, P ------- Y, P	US 5,650,632 A (COUFAL ET AL) 22 July 1997 (22-07-97), column 1, lines 14-16, column 3, lines 8-9, 22, 55-64, and column 4, line 31 to column 5, line 19.	12 ------------- 6-11, 13-20
Y	US 5,343,292 A (BRUECK ET AL) 30 August 1994 (30-08-94), abstract, column 1, lines 6-21 and column 3, lines 35-51.	16-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 DECEMBER 1997	29 JAN 1998

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	KATHLEEN DUDA
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A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

430/296, 327; 250/492.1, 492.2, 505.1; 359/559, 562, 564, 568, 590